Journal of Great Lakes Research xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

Erosion and deposition within Poyang Lake: evidence from a decade of satellite data

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ARTICLE INFO

Article history:
Received 17 February 2015
Accepted 22 December 2015
Available online xxxx

Communicated by Barry Lesht

Index words:
Poyang Lake
Erosion
Bottom topography
Three Gorges Dam
Remote sensing
Human impacts

ABSTRACT

Poyang Lake, an important wetland in the Ramsar Convention List, is the largest freshwater lake in China and an essential component of the Yangtze River system. The lake is increasingly experiencing serious water crises including seasonal desiccation, decreased wetland area, and water shortages, all of which are closely related to progressive changes in the lake's topography over recent years. Atime-series of bottom topography would contribute to our understanding of the lake's evolution during the past several decades. However, quality bathymetric data for Poyang Lake are scarce owing to the highly dynamic and turbid nature of its water. To resolve this limitation, we used a total of 146 medium-resolution satellite images to build annual and quasi-annual bottom topography maps of Poyang Lake during the period from 2000 to 2010 based on the well-established waterline method. Our results show that: (1)the average elevation of the lakebed relative to sea level has decreased by 14.4 cm/yr. from 2000 to 2010; and (2)the observed annual changes in the lakebed elevation were well correlated ($r = 0.84$) with measured changes in the lake's annual net sediment flux. The observed trends may be attributed to the impacts of human activities, especially the operation of the Three Gorge Dams, frequent sand mining, and the implementation of a large water conservancy project. This decade-long quantitative understanding of the lake's evolution and bottom topography elevations might assist both researchers and local policymakers in ecological management, wetland protection, and lake navigation safety.

Introduction

Poyang Lake, the largest freshwater lake in China, has prominent seasonal variations in water levels and surface area (Wang et al., 2013). As a well-known international wetland (it is on the Ramsar Convention List, 1992), Poyang Lake provides crucial environmental functions in relation to flood storage and biological diversity, and it plays other specialized ecological roles within the Yangtze River basin. During the past decade, driven byfactors such as sediment supplementation, hydraulic conditions, and human activities (De Leeuw et al., 2010; Hu et al., 2007; Rukavina and Zeman, 1987; Ye et al., 2013), Poyang Lake has undergone accelerated topographic changes over time and space. Consequently, Poyang Lake is being faced with increasingly serious water crises (*e.g.*, seasonal desiccations, diminished wetlands, community water shortages) (Gao et al., 2014). Therefore, a quantitative understanding of the lake's evolution and bottom topography would be useful not only from an economic perspective, but also from the perspectives of ecological, sustainable development, and environmental protection goals (Cooper etal., 2014; Feng et al., 2012; Hui et al., 2008).

Commonly used methods for mapping bottom topography include conventional field measurements (*e.g.*, ground surveying, ship-based echo sounding) and aerial survey methods (*e.g.*, airborne stereophotogrammetry, airborne light detection and ranging) (Hamilton et al., 1993; Hilldale and Raff, 2008; Studinger et al., 2004; Wang et al., 2009; Yousef et al., 2013). Although a high degree of accuracy is possible, the former methods are labor-intensive and subject to weather conditions and accessibility, which typically leads to infrequent and incomplete spatial–temporal sampling. The latter has a high potential but may also be restricted by weather conditions, as well as water levels and the high costs for updating elevation data (Gao, 2009).

Satellite images provide an alternative data source for mapping bottom topography and monitoring lake evolution. In this regard, the waterline method, which uses time-series of satellite images to construct a digital elevation model (DEM) of tidal flats, is a well-established topographical mapping technique for the inter tidal zone at the macro and meso scale (Liu et al., 2013b; Liu et al., 2013c; Mason et al., 1995; Mason et al., 1998; Mason et al., 2001). Similar to semi-diurnal or daily sea level variations in the coastal zone, some typical throughput type lakes (*e.g.*, Poyang Lake and Dongting Lake) show obvious seasonal water level variations. Therefore, it is possible to estimate a temporal sequence of bottom topography estimates for such lakes based on time-series satellite images (Feng etal., 2011; Hui et al., 2008; Yan et al.,

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http://dx.doi.org/10.1016/j.jglr.2015.12.012
0380-1330/

Please cite this article as: Zhang, S., et al., Erosion and deposition within Poyang Lake: evidence from a decade of satellite data, J. Great Lakes Res. (2016), http://dx.doi.org/10.1016/j.jglr.2015.12.012

2014). Feng et al. (2011) estimated the bottom topography of Poyang Lake based on MODerate-resolution Imaging Spectroradiometer (MODIS) images. However, considering the limitation of MODIS images in terms of the spatial resolution, the accuracy of the bottom topography could be further improved for more effective monitoring of erosion and deposition variation. In an early demonstration of this remote bathymetry technique for a lake, Hui et al. (2008) used eight Landsat Thematic Mapper (TM) images spanning a one-year period to construct a quasi-annualDEM of Poyang Lake, thus proving that it is feasible to use Landsat images for constructing lake bottom topography. However, the lack of time-series data still limited a better understanding the topographic evolution.

The present study aims to analyze the erosion–deposition variation trends of Poyang Lake with the support of remote sensing (RS) and geographic information system (GIS) techniques. Specifically, the objectives of this study are as follows: (1)to map the annual/quasi-annual topography of Poyang Lake from 2000 to 2010 by using multi-source and multi-temporal medium spatial resolution satellite images; (2)to analyze the interannual variability and process trends in the bottom topography; and (3)to identify the factors that are likely to impact the lake's erosion–deposition variation trends.

Study site

Poyang Lake (28°22′–29°45′N, 115°47′–116°45′E), which has a capacity of 3.00×10^{10} m^3 in the wet season, is located on the south bank of the middle reaches of the Yangtze River (Changjiang River) (Gao et al., 2014). The lake is an important regulator for the main stem of the Yangtze River because it gathers water runoff from five contributing rivers (including the Gan River, Fu River, Xin River, Rao River, and Xiu River, henceforth referred to as the "Five Rivers") and then feeds the Yangtze River at Hukou through a northern channel (Fig.1). During the flood season (from July to September), the Yangtze River sometimes flows backward into the lake (Lei et al., 2011; Ye et al., 2011) as river levels rise.

Poyang Lake is a water carrying, throughput type, seasonal lake that is affected by the water levels of the Yangtze River and the Five Rivers. Seasonal variation of the lake's water levels and surface area is significant. For instance, at the Hukou Hydrological Station, the average water level range between the wet season (from April to September) and the dry season (from October to March) is approximately 12 m (Ye et al., 2011). Poyang Lake expands to its maximum size during the wet season, but shrinks to little more than a river channel during the

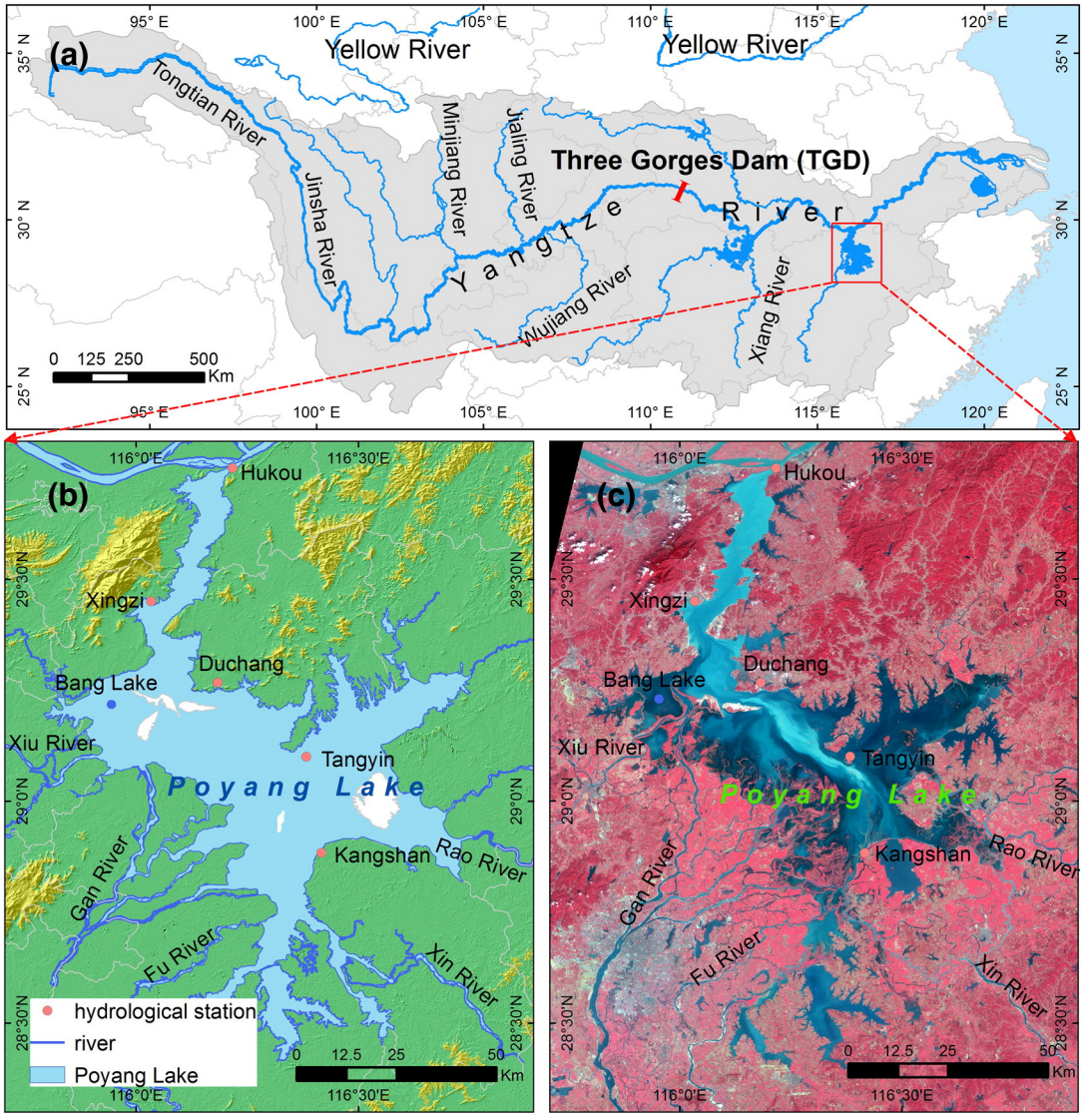

Fig.1. Location of Poyang Lake in the (a)Yangtze River basin and (b)Poyang Lake region, Jiangxi Province, China. Its maximum size during the wet season of 2010 is shown by the blue polygon, which was derived from the satellite image with the highest water level in 2010. (c)Poyang Lake region in a sample Landsat-8 OLI image (taken on October 8, 2014) with normal water levels.

Please cite this article as: Zhang, S., et al., Erosion and deposition within Poyang Lake: evidence from a decade of satellite data, J. Great Lakes Res. (2016), http://dx.doi.org/10.1016/j.jglr.2015.12.012